SATELLITE COMMUNICATIONS

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5

MODULATION AND MULTIPLEXING TECHNIQUES FOR SATELLITE LINKS

Communications satellites carry telephone, television (TV), and data signals. Obviously data are always transmitted digitially, but telephone signals may be analog or digital. Digital television is used for teleconferencing, but entertainment TV is still analog. A satellite link will normally relay many signals from a single earth station; these must be separated to avoid interfering with each other. This separation is called *multiplexing*, and its most common forms are *frequency division multiplexing* (FDM) and *time division multiplexing* (TDM). In the first case the signals pass through the transponder on different frequencies; in the second they enter it at different times. Theoretically either multiplexing technique could be used with analog or digital modulation, but TDM is easier to implement with digital modulation and FDM is more convenient with analog modulation. Since choices of multiplexing and modulation techniques cannot be made separately, this chapter treats the two topics together. The next chapter discusses the related problem of multiple access, which is how to allow signals from different earth stations to use the same satellite without interference.

Many books have been written on modulation, demodulation, and multiplexing, and we lack the space to treat these topics in complete detail here. This chapter will review the characteristics of the signals commonly carried by satellites and stress those aspects of modulation and demodulation that are important to satellite link engineering.

5.1 ANALOG TELEPHONE TRANSMISSION

While digital modulation has some inherent advantages over analog frequency modulation (FM) for telephone signals, much of the early investment in the Intelsat

)f a Bell T1 digital multiplexer. e channels, which, for now, we ther and have exactly the same l flow into buffers and wait for eads them out and inserts them transmitted by sending a 1(the hannel 1, then one 8 bit word word from channel 24. Then a multiplexer forms frame 2 by by the words from each chan- ess continues. When the buffers erframe has been sent and the

er must sort out the bits in each outgoing channel. It must also superframe) that it is receiving. by assuming that the incoming instant the last bit has entered of Figure 5.30. The multiplexer annel into their own individual eir separate paths. At this point

gister, which, at the completion ment word. If it does not, then c. When this occurs the demul- s called *reframing*. In it the de- ts until it finds one that is going 00 100011011100 pattern. Ob- of frame alignment bits and the transmitted within each frame, e FAW is transmitted with one 50 ms [21], which is sufficiently peech in the 24 channels when

channels must go the signaling inate the data channels. In the obbing" the least significant bit aling channels A and B, respec- ed by a form of 7-bit PCM and at an 8 kbps rate.

agreed upon standard interna- s recommended a standard 1.544 T1) and a 2.048 Mbs 30-channel

system [23]. For details on their slot and bit organization the reader should consult reference 24.

Channel Synchronization in TDM

Our explanation of the T1 system made the tacit assumption that all 24 incoming PCM channels were synchronized with each other and running at the same bit rate. This condition would hold if the voice channels had reached the originating earth station in analog form and had been digitized by modulators running on a common clock. But if the channels came into the station in digital form, their synchronization would not be guaranteed. They may be resynchronized for TDM transmission by a technique called *pulse stuffing* [1, 18].

In pulse stuffing the incoming words for each channel flow into an elastic buffer. There is one such buffer per channel, and each buffer can hold several words. The multiplexer reads words out of the buffer slightly faster than they come in. Periodically the multiplexer will go to the buffer and find less than a full word remaining. When that happens it inserts a dummy word called a *stuff word* into the frame in place of the word it would have taken from the buffer. At the same time it places a message on the signaling channel that states that a stuff word has been inserted. When the demultiplexer at the other end of the link receives the message it ignores the stuff word. When it is time for the next frame to be sent the buffer will have more than a full word waiting for transmission.

5.9 SUMMARY

Multiplexing is the process of separating the channels transmitted by a single earth station to prevent them from interfering with each other; its most common forms are frequency division multiplexing (FDM) and time division multiplexing (TDM). In the first case the channels are separated in frequency and in the second case they are separated in time.

Most analog telephone channels are transmitted over satellite links using frequency division multiplexing with frequency modulation (FDM/FM). In this method individual voice channels (nominally containing frequencies between 300 and 3400 Hz) are "stacked" in frequency by a multiplexer and the resulting multiplexed telephone signal is used to frequency modulate an uplink carrier. At the downlink earth station, an FM demodulator recovers the multiplexed signal and a demultiplexer recovers the individual channels.

An FM demodulator is characterized by a threshold. Provided that a satellite link's overall carrier-to-noise ratio (C/N) is above this threshold, the signal-to-noise ratio (S/N) of the demultiplexed voice channels will be significantly greater than the incoming (C/N). This effect is called FM improvement. Additional improvement in (S/N) may be obtained through preemphasis and deemphasis. Deemphasis decreases the noise power output of an FM demodulator; preemphasis distorts the multiplexed telephone signal before transmission to compensate for the deemphasis at the downlink earth station.

6

MULTIPLE ACCESS

Multiple access is "the ability of a large number of earth stations to simultaneously interconnect their respective voice, data, teletype, facsimile, and television links through a satellite" [1]. To quote a recent survey article, "The multiple-access problem is fundamental to satellite communications because it is the means by which the wide geographic coverage capability and broadcast nature of the satellite channel are exploited. It affects all elements of the system, determines the system capacity and flexibility, and has a strong influence on costs" [2]. The basic problem involved is how to permit a changing group of earth stations to share a satellite in a way that optimizes (1) satellite capacity, (2) spectrum utilization, (3) satellite power, (4) interconnectivity, (5) flexibility, (6) adaptability to different traffic mixes, (7) cost, and (8) user acceptability [1]. Usually all of the elements in this list cannot be optimized and some may have to be traded off against others.

Classically there are three multiple access techniques, illustrated in Figure 6.1. In *frequency division multiple access* (FDMA), all users share the satellite at the same time, but each transmits in its own unique frequency band. This is most commonly employed with analog modulation, where signals are present all the time. In *time division multiple access* (TDMA), the users transmit in turn in their own unique time slots. While transmitting, each occupant has exclusive use of one or more transponders. The intermittent nature of TDMA transmission makes it particularly attractive for digital modulation. In *code division multiple access* (*CMDA*), many earth stations simultaneously transmit orthogonally coded spread-spectrum signals that occupy the same frequency band. Decoding ("despreading") systems receive the combined transmissions from many stations and recover one of them.

In all three classical multiple access schemes some resource is shared. If the proportion allocated to each earth station is fixed in advance, the system is called *fixed access* (*FA*) or *preassigned access* (*PA*). If the resource is allocated as needed in response to changing traffic conditions, the multiple access arrangement is termed *demand access* (*DA*). Demand access blurs some of the distinction between

synchronization. Demodulation and remodulation at the satellite avoids any retransmission of uplink noise, and the use of a single digitally modulated carrier on the downlink eliminates the need for backoff. Synchronization is provided by the satellite itself; receiving earth stations simply track the slow changes in reference burst times that result from orbital motion. Hughes claims a 6-dB (C/N) advantage for this system over conventional FDMA—5 dB from the absence of a backoff and 1 dB from the elimination of retransmitted uplink noise.

As described earlier in this chapter, most TDMA technology and operating procedures evolved under the implicit assumption that all earth stations in the network would be able to receive all transmissions as they were relayed by the satellite. This provides complete interconnectivity; any station can transmit to any other station at any time. But the spot beams that will be required for frequency sharing and to provide the necessary fade margins (see Chapter 8) and large E_b/N_0 values for high data rates at frequencies above 10 GHz will destroy this interconnectivity. Stations will be able to hear only those transmissions that come down in their own local spot beam. The satellite will have to incorporate the necessary equipment to interconnect different uplink and downlink spot beams in response to changing traffic demands. This is called *satellite-switched* TDMA (SS-TDMA). See reference 44 for a general discussion.

The number of spot beams that a spacecraft can provide is limited. An alternative to leaving spot beams on fixed locations is to have a single scanning beam that continuously scans a satellite's service area. This requires that the spacecraft have the capability to receive a traffic burst from one location, store it, and retransmit it when the scanning beam is on the intended recipient. Such systems have been proposed for NASA's ACTS (Advanced Communications Technology Satellite) spacecraft and for INTELSAT VI [45].

6.8 SUMMARY

Multiple access is the process by which a large number of earth stations interconnect their links through a satellite. In frequency division multiple access (FDMA), stations are separated by frequency, while in time division multiple access (TDMA), they are separated in time. In code division multiple access (CDMA), stations use spread-spectrum transmissions with orthogonal codes to share a transponder without interference. Multiple access may be preassigned or demand, depending on whether or not it responds to changing traffic loads.

Frequency division multiple access with frequency division multiplexing and FM modulation (FDM/FM/FDMA) is the oldest and currently (1984) the most widely used multiple access scheme. In it each earth station is assigned frequency bands for its uplink transmissions. Because of the TWT backoff required to reduce intermodulation distortion, the spectral efficiency (i.e., the number of channels that can be carried per MHz of bandwidth) degrades with the number of stations that access a transponder. Companded single sideband (CSSB) is an FDMA scheme in which each voice channel requires only 4 kHz at RF for transmission. Besides high spectral efficiency, its main advantage over FDM/FM/FDMA is that CSSB

performance depends only on the number of channels carried and not on the number of accesses. CSSB is more sensitive to interference than FDM/FM/FDMA, and this may alter the relative advantages of the two analog FDMA schemes in practical applications.

In time division multiple access (TDMA), earth stations transmit in turn. Since only one carrier is present at a time, no TWT backoff is required and thus full transponder EIRP is available. TDMA performance does not degrade with the number of accesses. TDMA transmissions are organized into frames; a frame contains one or two reference bursts that synchronize the network and identify the frame and a series of traffic bursts. Each participating station transmits one traffic burst per frame. Frames are grouped into larger structures called superframes. Frames, superframes, and individual traffic bursts are identified by standardized bit sequences called unique words. One of the major technical problems in implementing TDMA is synchronization. Once synchronization is acquired, it must be maintained dynamically to compensate for orbital motion of the spacecraft.

In code division multiple access (CDMA) stations transmit at the same time and in the same frequency bands using spread-spectrum (SS) techniques. CDMA avoids the centralized network control required for synchronization in TDMA, but it is difficult to implement in practice. Its use will probably be limited to those systems (chiefly military) that must employ SS for reasons other than multiple access.

The number of channels required to carry an anticipated volume of traffic between earth stations may be calculated from the Erlang B model. In demand assignment systems, these channels may be drawn from a pool available to all members of a network. This requires fewer total channels than if each station is permanently assigned the number of channels needed to carry the anticipated volume of traffic between it and all of the other members of the network. The number of voice channels required can be further reduced if the network reassigns channels during the quiet periods between speech spurts. This technique is called speech interpolation.

In applications like interactive computing that are characterized by burst transmissions separated by long quiet periods, random access may be used. Each station transmits at will, waits for an acknowledgment, and transmits again if none is received. This eliminates the requirement for centralized control of a demand-access system. Such schemes are called ALOHA systems after the first successful implementation.

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